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THE EFFECT OF CROP SEQUENCE AND ASSOCIATION ON THE YIELD AND QUALITY OF WHEAT.

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THE EFFECT OF CROP SEQUENCE AND ASSOCIATION ON THE YIELD AND QUALITY OF WHEAT.

by

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INTRODUCTION.

During the past few years considerable attention has been directed to the maintenance and improvement of the quality of wheat in Western Canada. Since Canadian wheat owes its value in the world's markets to its high quality, it is obvious that any study of the factors affecting this quality is of great importance. At the University of Alberta a number of projects, of which this investigation is one, relating to wheat quality are being carried out by the Department of Field Crops and the Associate Committee on Grain Research of the National Research Council of Canada.

It is well known that the yield and composition of wheat is influenced by the previous crop. It has been frequently observed in Western Canada and elsewhere that the growth of wheat after timothy was not as vigorous as when following other grasses or legumes. On the other hand a number of workers have found that alfalfa and other legumes usually exerted a beneficial effect on succeeding grain crops.

In view of these observations an experiment was designed in 1927 to determine the effect of alfalfa (*Medicago sativa* L.), brome grass (*Bromus inermis* Leyss.), timothy (*Phleum pratense* L.), and western rye grass (*Agropyron tenerum* Vasey) on the yield and quality of subsequent wheat crops. Timothy, the most common cultivated grass in North America, was early introduced into Alberta, and is still widely grown in spite of its inability to withstand drought. Brome and western rye grass are two crops whose hardiness and drought resistance render them the leading grasses of Western Canada. Alfalfa was added to this series of experimental crops as a standard of comparison, because it is widely recognized as perhaps the best of all crops from the standpoint of sequence effects.

It was hoped by this experiment not only to throw light on some of the theoretical considerations of crop sequence, but also to obtain information of considerable practical value. As mixed farming becomes more prevalent in the West, as it inevitably will, the use of rotations including a forage crop will be greatly extended. In these rotation systems the question of the effect of different forage crops on wheat yield and quality will be of great importance. These studies are of particular importance to Central and Northern Alberta, where conditions are favorable for mixed farming, and the quality of the wheat is usually inferior to that produced on the open plains.

It was also believed that a study should be undertaken of the effect of interplanting with legumes on the yield and quality of wheat. A few workers have studied the effect of the association of legumes and non-legumes, but their work has been

largely confined to yield and protein content of grasses and cereals other than wheat. The increased protein content of the associated non-legume, found by some investigators, with its consequent bearing on the subject of wheat quality, gave rise to the question whether it would be possible to improve the yield or quality of wheat by interplanting with legumes.

REVIEW OF LITERATURE

Effect of Crop Sequence on Yield and Quality.

That the growth of certain crops will affect the yield and composition of a succeeding crop has been popularly believed for a long time and has received much experimental confirmation. This effect may be beneficial or deleterious depending on the nature of the preceding crop and on the environment. Since this experiment in crop sequence was confined to the effect of alfalfa, brome, timothy, and western rye grass on wheat we shall confine the references largely to work done with these crops.

There is no dearth of experiments demonstrating the superiority of legumes in increasing the yields of subsequent wheat crops. Very little work, however, has been done on the important factor of quality. At the Indiana station (35) as an average for 100 crops on 8 experiment fields in that state for 20 years, wheat after a legume has produced 5 bushels more per acre than similar rotations where no legume was grown.

An early Canadian experiment at the Ontario Agricultural College (39) resulted in wheat after alfalfa giving a 50 per cent higher return than after timothy.

The experiments with crop rotations on the prairies do not afford a comparison over a long period of years between the effect of a legume and a non-legume hay crop on the following wheat crop. At Brandon (24) the yield of wheat after alfalfa has been higher than after grasses, and at the University of Alberta (26) wheat following alfalfa has yielded better than following timothy.

Mangels (23) found in North Dakota that wheat following sweet clover had a higher percentage of protein than wheat after

non-legumes. Call (3) working in Kansas, reported the protein content of wheat was materially lower where this crop followed brome grass than where it followed alfalfa.

The explanation for the beneficial effects of legumes on wheat yield and quality appears to lie in the increased nitrate content of the soil and conditions favorable for nitrification consequent upon growing these crops. A number of investigators (19,21,22,36,38) have demonstrated that the production of nitrate nitrogen in soil under a legume such as alfalfa is higher than under grass crops, and that the effect persisted for some time, at least up to two years (38) after the sod was broken.

Löhnis (17) found increases in crops after legumes were almost or quite as high when the legumes were harvested as when they were plowed under as green manures. Stimulation of bacterial activities by growing legumes was evidenced by marked increases in the total number of soil organisms, by rapid multiplication of such forms as B. radiobacter, and by greatly increased nitrification. Actinomyces and fungi likewise became more numerous under the influence of legumes. The favorable change in the soil flora persisted and became even more pronounced during the next two or three months after the legumes had been harvested. Longer intervals, however, and especially a thorough drying of the soil, caused a more or less complete disappearance of these beneficial changes.

When we compare the effects of the grasses on succeeding wheat crops the little work done on this question at Brandon and University of Alberta has indicated western rye has an advantage over brome. At Beaverlodge, in 1923,1924, and 1926 the yield of

barley after western rye, and in 1927 of wheat after western rye was greater than the yield of these respective crops after brome.

The depressive effect of timothy on succeeding grain crops has been noticed by a number of investigators (19,21,22,26,36) and studied in considerable detail at Cornell University. It has been demonstrated that a plant residue like timothy, containing a large amount of carbonaceous matter and a low nitrogen content, when incorporated with soil causes a temporary disappearance of nitrate nitrogen with resulting detrimental effects on succeeding crops. The explanation put forth is that the plant is forced to compete with soil organisms which use nitrates for their own metabolism, and that these organisms are greatly stimulated in growth by the presence of large supplies of energy - forming material. The available nitrate content of the soil is thus reduced, temporarily at least, by the transformation of available nitrogen into non-available forms, through the agency of micro-organisms. It has also been shown (36) that the decomposition of timothy is extended over a much longer period than that of other crops, particularly legumes, and meanwhile the nitrate nitrogen of the soil is depressed.

That this effect may be modified by climatic conditions is indicated by the results of an experiment on the residual effect of sods carried out at the Beaverlodge station a few years ago, and found in the reports of the Superintendent for 1923, 1924,1926, and 1927. In 1923 and 1924, barley following western rye was higher in yield and protein content than when following brome, and considerably higher than the same crop following timothy. In 1926 and 1927, the yield of barley and wheat after timothy sod was slightly higher than that following western rye or brome grass. In the latter two years the weather following

the breaking of the sods and previous to seeding to grain the next spring was wet, in marked contrast to conditions in 1923 and 1924. During the warm humid season all sods rotted equally well and no adverse effect of timothy was noted.

It might be expected that previous work on crop sequence would have demonstrated that the crop which made the heaviest demands on soil moisture and nutrients, particularly nitrates, would be followed by the lowest yield of wheat. The root systems of alfalfa, brome, and western rye grass as shown by Weaver (33) are much more extensive than those of timothy. Those of western rye and brome are also more intensively branched. In an experiment at Olds, Hopkins (13) found that brome grass reduced the soil moisture to 9 per cent while timothy reduced it only to 15 per cent. Recent work by Duley (7), and Kiesselbach, Russell and Anderson (14), has shown that alfalfa greatly depletes subsoil moisture and that low yields of this crop on old stands can be attributed to this fact. It is quite easy to see that under certain conditions the relative depletion of soil moisture by previous crops would influence the growth of wheat. Alfalfa removes more nitrogen from the soil than timothy, yet, the experiments at Edmonton and Beaverlodge, as well as the Cornell results, indicate that the legume is followed by larger crops of grain.

Finally the effects of crop sequence have been at various times ascribed to toxic decomposition products of plant residues . It has been demonstrated by a number of workers that such products may arise under unfavorable soil conditions, such as poor aeration, and exert a toxic effect on subsequent crops. One of the latest contributions along this line is by Collison and Conn (6) who found two harmful factors associated with straw and other plant residues. First a toxic chemical agent acted upon the seedling

plants immediately after germination, although it did not have a very pronounced effect in the presence of much colloidal matter, as in clay soils. The second was the biological factor already discussed due to the stimulation of micro-organisms which compete with plants for nitrates. They do not state whether they found any difference between the effects of timothy and of alfalfa residues.

Effect of Association on Yield and Quality.

Very little work has been done on the effect of association with legumes on yield and quality of non-legumes. A few experiments have been reported where other grains or grasses were grown with legumes.

Among the first to report a beneficial effect of association with legumes were Lyon and Bizzell (20) who found the protein content of timothy grown with alfalfa, and oats grown with peas was higher than when these non-legumes were grown alone.

Lipman (16) also found oats were benefitted by association with peas, and stated that non-legumes, under favorable conditions, may secure large amounts of nitrogen from legumes, even though this may not be indicated by an increased proportion of nitrogen in the dry matter of the non-legume.

Ellett, Hill, and Harris (9) obtained contradictory results in greenhouse and field experiments. In the greenhouse when corn and beans were grown together the protein content and yield of the former were benefitted. In the field,however, the corn and bean association was detrimental to the growth of the corn.

Stallings (30) found wheat grown with inoculated soybeans many under favorable conditions obtain considerable amounts

of nitrogen from the latter.

On the other hand, Westgate and Oakley (34) report that the protein content of wheat was slightly lowered when grown with crimson clover.

Lyon (18) reported the use of peas planted with oats was detrimental to the yield of the latter, but was largely offset by an increase in subsequent crops in the rotation.

Duley and Miller (8) grew a mixture of corn and soybeans, or corn and cowpeas on twenty-five experimental fields in Missouri. The yield of corn was decreased about one bushel per acre by this practice.

The question might be raised whether the presence of a legume might not stimulate growth of micro-organisms with resulting benefit to both legume and non-legume.

Starkey (31) has indicated that while different plants exert different degrees of influence upon the soil organisms, in a manner as yet not fully understood, legumes may exert no more pronounced effects upon the organisms than do non-legumes.

In conclusion, information in regard to the influence exerted by legumes when grown in association with wheat is meagre, and no experiment showing the combined effect on yield and quality has been reported.

ANALYTICAL METHODS

grain ?

Sampling.- Samples of hay, straw, stubble and roots, and wheat, secured as outlined in the experiments, were ground finely in a Wiley mill and a representative sample obtained from this material.

Moisture.- The samples of hay, straw, and plant residues were dried *in vacuo* by the method outlined for feeding stuffs in Methods of Analysis, Assoc. Official Agr. Chem., 1920. The wheat and flour samples were dried in an air oven for one hour at 130° C. [illegible]

Total Nitrogen.- The total nitrogen on all material was determined by the Kjeldahl method, using the procedure recommended by Paul and Berry (27). Protein of wheat and flour = N x 5.7; protein of hay, straw, and plant residues = N x 6.25.

Grade.- The grade reported is the official grade assigned to the samples by the Dominion Grain Inspector at Edmonton.

Weight per Bushel.- The weight per bushel was determined by weighing the wheat by the beam method in an Imperial Quart Bucket. Uniform and accurate results were obtained by employing exactly the same quantity of grain and identical conditions in the packing of the grain into the bucket.

Kernel Texture.- The kernel texture was determined by classifying a representative sample of one thousand kernels into hard, piebald, and starchy on the basis of external appearance. The result was checked by cutting the kernels with a Marks grain tester and observing the appearance of the cut

surface.

Crude Fibre.- The amount of crude fibre in the plant residues was determined using the method of Bidwell and Bopst (1).

Ether Extract.- The ether extract was determined by the method outlined for analysis of feeding stuffs in Methods of Analysis, Assoc. Official Agr. Chem., 1920, with modifications developed in full in this laboratory. Alundum thimbles of fine porosity were used instead of the official papier mâché, and extraction was carried out for 48 hours instead of 16.

Ash.- The amount of ash in plant residues was determined as follows:- 2 - gram samples of oven dried material were weighed directly into previously ignited and weighed alundum crucibles which were placed in a muffle furnace at 600° C. The crucibles were removed in ½ hour, cooled, and stirred full thoroughly with a glass rod to break up the ash and reduce the amount of occluded carbon. The heating was repeated as before, about ½ hour. The crucibles were removed to a vacuum dessicator for twenty-minutes and weighed in a weighing bottle. Duplicates were required to check within 2%.

Milling.- The milling was done in an experimental mill, using the standard process of the Associate Committee on Grain Research described by Geddes (10).

Baking.- Baking was done in an experimental bakeshop and

the procedure was that of the American Association of Cereal Chemists (2) with the modifications used by the Associate Committee on Grain Research, described by Larmour and McLeod (15) and Geddes (10). The method of scoring loaves used by the Associate Committee on Grain Research has also been described by Larmour and McLeod (15).

THE EFFECT OF ALFALFA AND VARIOUS GRASSES ON YIELD AND QUALITY OF SUCCEEDING WHEAT CROPS.

Plan of Experiment and Production of Material

The experiment to determine the effect of alfalfa and various grasses on wheat yield and quality was designed in 1927. This project is being carried on in co-operation with the Soils Department of the University of Alberta who are endeavouring to determine the effect of different crops on chemical and biological changes in the soil. Block 7B in the Investigation Field on the University Farm which had been fallowed the previous year was seeded June 10-21,1927, in the following manner.

The block was divided into three sub-blocks,each 200 by 205 links, divided by the Latin square system into 16 plots each 50 by 50 links. The extra 5 links in width of the block were distributed between three paths running north and south, each 1 2/3 links wide. At harvest a 2 - link margin around each plot was discarded, leaving the net size 46 by 46 links.

The plots were similar in topography and soil characteristics the only exception being a depression at the north-west corner of the block where part of a plot must occasionally be discarded owing to flooding in the spring.

Sub-blocks are designated by Roman numerals I,II,III, from north to south. Within each sub-block plots number from north to south in four groups containing respectively Nos.- 1-4, 5-8, 9-12, 13-16, beginning at the north-east corner.

The following crops were seeded on each sub-block in quadruplicate by limited random distribution:-

Timothy - Swallow, 8 lbs. per acre.

Western Rye Grass - Fyra, 10 lbs. per acre.

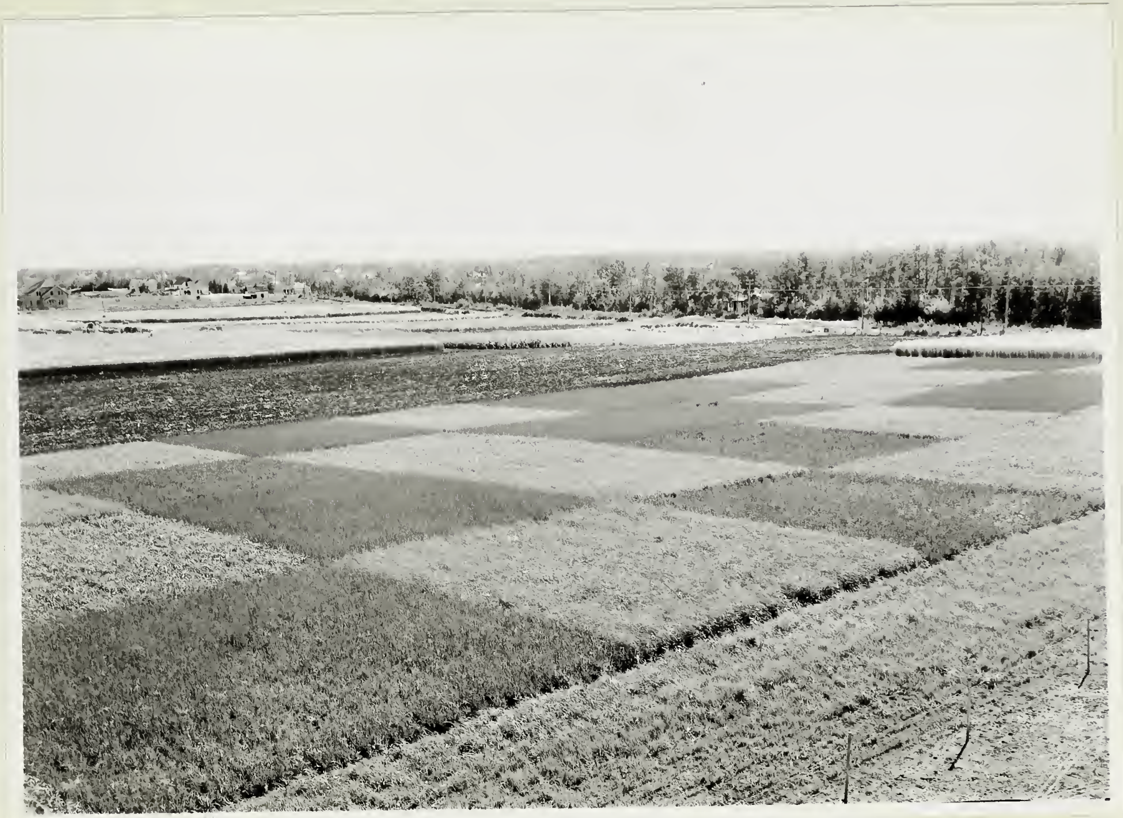


Plate I.- View of a portion of Sub-blocks I,II, and III on September, 1927,showing distribution of plots.

Brome grass - Superior, 12 lbs. per acre.

Alfalfa - Grimm (inoculated), 10 lbs. per acre.

These crops were seeded east and west, 50 rows 1 link apart on each plot, beginning ½ link from the boundary of each plot.

The plan below shows the numbering and arrangement of plots and crops:

N←

Sub-block I				Sub-block II				Sub-block III			
1 T	2 A	3 B	4 WR	1 A	2 B	3 T	4 WR	1 T	2 A	3 B	4 WR
5 WR	6 B	7 T	8 A	5 WR	6 A	7 B	8 T	5 A	6 B	7 WR	8 T
9 B	10 WR	11 A	12 T	9 B	10 T	11 WR	12 A	9 WR	10 T	11 A	12 B
13 A	14 T	15 WR	16 B	13 T	14 WR	15 A	16 B	13 B	14 WR	15 T	16 A

Plate I shows a view of a portion of the three sub-blocks.

Soil samples.- Three borings are taken per plot for the surface soil, two borings per plot for the subsurface and subsoil. Composite samples are made for each crop on each sub-block, or twelve composites for each depth of sampling, or thirty-six composites in all at each time of sampling the whole block.

For the first season, samples were taken just before seeding and again at monthly intervals until fall. When a cutting of hay was made one sampling coincided with the time of cuttin

Sampling is being continued throughout later seasons until a second wheat crop following breaking has been taken.

Moisture and nitrates are determined on all samples; total nitrogen once per season.

In 1929, the rate of nitrification of soil from Sub-block I was determined under laboratory conditions by the Department of Soils, which Department also made a study of the soil micro-organisms occuring under the following crops:-

Alfalfa, Sub-block III
Timothy, Sub-block III
Western Rye, Sub-block III
Wheat following alfalfa, Sub-block I
Wheat following timothy, Sub-block I
Wheat following western rye, Sub-block I.

Hay Yields.- The hay is cut when the grasses have passed full bloom stage. Margins are discarded, the green weight per plot is recorded, samples taken for analysis, and the crop removed at once.

If a second cutting of hay becomes necessary it is treated in a similar manner.

Hay Samples.- Samples of 1000grams - are taken from each plot. These are carried to the air-dry stage, weighed, combined for each crop on each sub-block (making 3 samples of each crop or a total of 12 samples), ground and oven-dried. Moisture and total nitrogen are determined.

In 1928 the hay samples were not combined but analysed separately for each plot to obtain a measure of variability.

The samples are dried quickly to prevent serious losses by respiration and enzyme action. In the absence of special equipment, rapid drying was secured by placing the samples in racks around a stove in a small room in the barn. After drying, before weighing and grinding in the Wiley mill, the samples were allowed to stand at room temperature for a few days to come to approximate equilibrium.

Breaking.- Sub-block I was broken on July 23,1928, immediately after cutting the hay (sod 1 year old). Sub-block II will be broken at the corresponding time in 1930 (3 years old); and sub-block III in 1932 (5 years old). In breaking, the sod was turned over flat, packed at once, and prepared for seeding wheat next spring.

Sod Samples.- Just after cutting hay and before breaking, 4 sods per plot are taken, each $\frac{1}{2}$ square foot in area (8 inches astride the rows by 9 inches long) and 6 inches deep. These are measured accurately; the soil washed out promptly, before fermentation occurs; and the residues are air-dried rapidly, and weighed to get an estimate of variability. Roots and stubble are divided carefully at the crown and composites of roots and stubble are made separately for each crop (8 composites per sub-block). These are weighed, ground, and analysed for moisture, total nitrogen, crude fibre, ether extract and ash.

Following Crops.- Wheat is planted on each sub-block the spring after breaking, and again on spring-plowed stubble the following spring. (That is, the last crop of wheat will be harvested from Sub-block III in 1934). Marquis wheat was seeded May 4, 1929, on Sub-block I. The crop from each plot, trimmed as before to 46 by 46 links, is harvested and threshed

separately. Straw and grain are weighed, 300 gram samples of each are taken from each plot and composites representing preceding crops are made (4 straw and 4 grain composites per sub-block). These are ground and analysed for moisture and total nitrogen. Complete milling and baking tests are carried out on the grain. All cultural operations and all plant sampling and analyses are carried out by the Department of Field Crops. All soil sampling and analyses are carried out by the Department of Soils.

Yield and Composition of Hay crops, 1927-29.

Hay crop of 1927.- Although the plots were seeded in the middle of June (10th - 21st) the plants had grown sufficiently to take a cutting of hay by September 8. The data on the yield and protein content of the hay are given in Table I.

The data on the yield and protein content of the hay for 1927, 1928, and 1929 are given in the following tables. A knowledge of this is of importance in a study of the relative sequence effects of the four crops, since it gives a measure of the draft which these make upon soil moisture and nutrients, among the latter more especially the nitrates. Incidently it furnishes a comparison of these four crops from the standpoint of their suitability as forage crops under our conditions. Nor must we lose sight of this aspect of the subject, inasmuch as no crop, no matter how excellent its effect may be on succeeding grain crops, is likely to become popular if its inherent value is inferior to that of other forage crops.

Table I. - Yield and protein content of hay, 1927.

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed	
				per sub-block.	per acre.
		lbs.	%	lbs.	lbs.
Sub-block I					
Alfalfa	2	30			
	8	39			
	11	11			
	13	23			
	Av.	26	3.60		
	Total	103		3.7	43.7
Brome	3	53			
	6	49			
	9	32			
	16	39			
	Av.	43	3.45		
	Total	173		6.0	70.9
Timothy	1	59			
	7	68			
	12	48			
	14	46			
	Av.	59	2.06		
	Total	221		4.5	53.2
Western rye	4	73			
	5	57			
	10	54			
	15	35			
	Av.	55	2.67		
	Total	219		5.8	68.5
Sub-block II					
Alfalfa	1	35			
	6	34			
	12	16			
	15	14			
	Av.	25	3.60		
	Total	99		3.6	42.5

Table I - (Continued)

Crop	Plot No.	Yield (Dry basis)	Nitrogen in dry hay.	Nitrogen removed	
				per sub-block.	per acre.
		lbs.	%	lbs.	lbs.
Brome	2	50			
	7	34			
	9	36			
	16	37			
	Av.	39	3.48		
	Total	157		5.5	65.0
Timothy	3	57			
	8	60			
	10	50			
	13	38			
	Av.	51	1.81		
	Total	205		3.7	43.7
Western rye	4	51			
	5	66			
	11	49			
	14	53			
	Av.	55	2.32		
	Total	219		5.1	60.3
Sub-block III					
Alfalfa	2	26			
	5	24			
	11	33			
	16	37			
	Av,	30	3.72		
	Total	120		4.5	53.2
Brome	3	41			
	6	38			
	12	31			
	13	38			
	Av.	39	3.47		
	Total	148		5.4	63.8
Timothy	1	54			
	8	52			
	10	65			
	15	66			
	Av.	59	1.98		
	Total	237		4.7	55.5

Table I.- (Continued)

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed	
				per sub-block	per acre.
		lbs.	%	lbs.	lbs.
Western Rye	4	57			
	7	50			
	9	55			
	14	63			
	Av.	56	2.41		
	Total	225		5.4	63.8

Precipitation in the summer of 1927 was very favorable for the growth of hay as evidenced by the yields obtained in less than three months after seeding. Timothy and western rye gave the highest yields, followed by brome and alfalfa. The percentage of nitrogen is highest in alfalfa hay, followed by brome and western rye grass, with timothy containing the lowest percentage. The amount of nitrogen removed by the various crops depends of course on the yield and percentage of nitrogen present in the hay. Brome removed the greatest amount followed by western rye, timothy, and alfalfa in the order given.

Hay crop of 1928. First cutting.- The first cutting of hay in 1928 was made on June 10-11, with the exception of the brome which was cut on June 20. Samples were taken from each individual plot for the determination of nitrogen in order to obtain an estimate of the variability. The results are given in Table 2.

Table 2. - Yield and protein content of hay. First cutting, 1928.

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed per sub-block	Nitrogen removed per acre.
		lbs.	%	lbs.	lbs.
Sub-block I					
Alfalfa	2	94	2.72		
	8	89	2.34		
	11	62	2.86		
	13	97	2.64		
	Av.	86	2.77		
	Total	342		9.5	115.4
Brome	3	121	2.04		
	6	114	1.90		
	9	114	1.76		
	16	97	2.41		
	Av.	112	2.03		
	Total	446		9.3	108.7
Timothy	1	108	1.32		
	7	99	1.46		
	12	96	1.43		
	14	101	1.38		
	Av.	101	1.40		
	Total	404		5.6	66.2
Western rye	4	144	1.58		
	5	139	1.36		
	10	99	1.48		
	15	111	1.42		
	Av.	123	1.46		
	Total	493		7.2	85.1
Sub-block II					
Alfalfa	1	102	2.59		
	6	88	2.70		
	12	75	2.86		
	15	55	3.10		
	Av,	30	2.81		
	Total	320		9.0	106.3
Brome	2	116	2.06		
	7	94	2.08		
	9	107	1.95		
	16	94	2.13		
	Av.	103	2.06		99.2
	Total	411		8.4	

Table 2. - (Continued).

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed per sub-block.	Nitrogen removed per acre.
		lbs.	%	lbs.	lbs.
Timothy	3	105	1.46		
	8	90	1.46		
	10	92	1.44		
	13	98	1.45		
	Av.	96	1.45		
	Total	385		5.6	66.2
Western rye	4	117	1.45		
	5	132	1.54		
	11	104	1.50		
	14	117	1.48		
	Av.	118	1.49		
	Total	471		7.0	82.7
Sub-block III.					
Alfalfa	2	76	2.80		
	5	75	2.62		
	11	75	2.83		
	16	78	2.83		
	Av.	76	2.77		
	Total	304		8.4	99.2
Brome	3	102	2.08		
	6	99	2.06		
	12	81	2.12		
	13	103	2.06		
	Av.	96	2.08		
	Total	385		8.0	94.5
Timothy	1	108	1.34		
	8	110	1.32		
	10	105	1.46		
	15	99	1.42		
	Av.	105	1.39		
	Total	422		5.8	68.5
Western Rye	4	119	1.47		
	7	110	1.48		
	9	117	1.44		
	14	119	1.53		
	Av.	116	1.48		
	Total	465		6.9	80.3

The order of the crops with respect to yield is changed from that obtained in 1927. Western rye gave the highest yield, followed by brome, timothy, and alfalfa. The nitrogen content of the hays is lower than it was in 1927. This was to be expected since the cutting in 1927 was made at an earlier stage in the growth of the plants. However, the order of the crops remained unchanged. The total amount of nitrogen removed in the crop is greatest in alfalfa, followed by brome, western rye, and timothy.

There is surprisingly little variation in nitrogen content between the individual plots of the different crops. The only wide variations occur in the brome plots of Sub-block I (1.76% to 2.41%), and in the alfalfa of Sub-block II (2.59% to 3.10%). However it should be observed that the average for all the plots of brome on Sub-block I and of alfalfa on Sub-block II agrees very well with the averages from the other sub-blocks.

Hay crop of 1928.- Second cutting.- Sub-block I was plowed immediately after the first cutting of hay was removed. The growth on the other two sub-blocks warranted the cutting of a second crop of hay on September 21. As in the first cutting each plot was analysed separately for nitrogen. The yields and nitrogen content are given in Table 3.

Table 3.--Yield and protein content of hay, second cutting. 1928.

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed	
				per sub-block	per acre
		lbs.	%	lbs.	lbs.
Sub-block II					
Alfalfa	1	58	1.96		
	6	59	1.89		
	12	48	1.94		
	15	52	2.00		
	Av.	54	1.95		
	Total	217		4.2	49.6
Brome	2	50	1.26		
	7	61	1.44		
	9	36	1.21		
	16	59	1.46		
	Av.	52	1.34		
	Total	206		2.8	33.1
Timothy	3	32	1.50		
	8	27	1.45		
	10	16	1.40		
	13	16	1.49		
	Av.	23	1.46		
	Total	91		1.3	15.4
Western rye	4	46	1.89		
	5	51	1.80		
	11	46	1.94		
	14	56	1.99		
	Av.	50	1.91		
	Total	199		3.8	44.9
Sub-block III					
Alfalfa	2	51	1.89		
	5	53	2.00		
	11	51	1.90		
	16	57	2.28		
	Av.	53	2.02		
	Total	212		4.3	50.8
Brome	3	63	1.24		
	6	58	1.17		
	12	60	1.24		
	13	53	1.04		
	Av.	59	1.17		
	Total	234		2.7	31.9

Table 3, - (Continued)

Crop	Plot No,	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed per sub-block.	Nitrogen removed per acre.
		lbs.	%	lbs.	lbs.
Timothy	1	23	1.53		
	8	24	1.56		
	10	26	1.53		
	15	19	1.54		
	Av.	23	1.54		
	Total	92		1.4	16.5
Western rye	4	49	1.91		
	7	48	1.98		
	9	47	1.77		
	14	50	1.99		
	Av.	49	1.92		
	Total	194		3.7	43.7

In this cutting the yields were naturally lower than in the first cutting of 1928. Timothy gave a significantly lower yield than the other three crops. Between these three the differences are not great. In this cutting, as in that of 1927, there was considerable variation in yield between the replicate plots of the different crops.

The nitrogen content of alfalfa and brome was lower than in the first cutting while that of western rye was higher. As the plants were cut in an earlier stage than in the first cutting it was expected that the values for all crops would have been higher than in the first cutting. The percentage of nitrogen in the hay was highest in alfalfa, followed by western rye, timothy, and brome grass. This difference in the relative standing of the nitrogen content of the three grasses in this cutting compared with the two previous cuttings can only be attributed to the well known fact that the nitrogen content decreases with increase in

maturity of the hay. The timothy and western rye were not quite as far advanced in the stage of growth as brome at this second cutting.

The largest amount of nitrogen was again removed by the alfalfa and the lowest by the timothy. The order of the other two crops was reversed in comparison with the order of the first cutting.

Hay crop of 1929. First cutting.- The first cutting of hay in 1929 was made on July 16. The data of the yield and protein content are given in Table 4.

Table 4.- Yield and protein content of hay. First cutting, 1929.

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay	Nitrogen removed	
				per sub-block.	per acre.
		lbs.	%	lbs.	lbs.
Sub-block II					
Alfalfa	1	62			
	6	52			
	12	42			
	15	39			
	Av.	49	2.76		
	Total	195		5.4	64.
Brome	2	37			
	7	33			
	9	29			
	16	41			
	Av.	35	1.46		
	Total	140		2.0	24.
Timothy	3	9			
	8	4			
	10	6			
	13	10			
	Av.	7	2.08		
	Total	29		0.6	7.
Western rye	4	37			
	5	47			
	11	38			
	14	48			
	Av.	43	1.53		
	Total	170		2.6	31
Sub-block III					
Alfalfa	2	48			
	5	48			
	11	41			
	16	43			
	Av.	45	2.73		
	Total	180		4.9	58

Table 4. - (Continued)

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed	
				per sub-block	per acre
		lbs.	%	lbs.	lbs.
Brome	3	36			
	6	34			
	12	28			
	13	33			
	Av.	33	1.49		
	Total	131		2.0	24
Timothy	1	7			
	8	6			
	10	8			
	15	6			
	Av.	7	1.93		
	Total	27		0.5	6
Western rye	4	40			
	7	35			
	9	43			
	14	31			
	Av.	37	1.65		
	Total	149		2.5	30

Conditions for the production of hay in 1929 were very critical due to the extremely dry season. Timothy demonstrated its low-yielding capacity in dry seasons in a very striking manner. On the date of cutting, July 16, the timothy, which had made almost no growth since spring, was about 2 - 4 inches high. From a practical standpoint the yield of timothy was nil, since under ordinary farm conditions it would have been impossible to cut the hay.

The yields of the other crops, alfalfa being highest, followed by western rye and brome, demonstrate their excellent drought-resistant qualities.

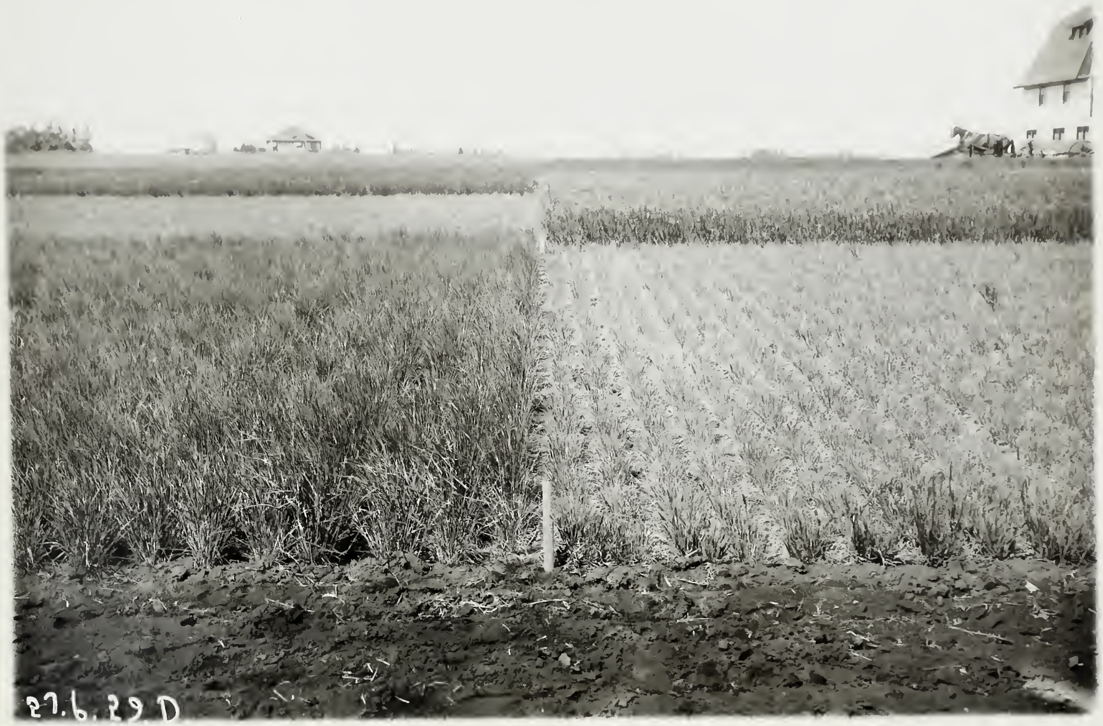


Plate 2.- Difference in growth between western rye grass (on left) and timothy (on right) during the dry season of 1929. Brome grass in background.

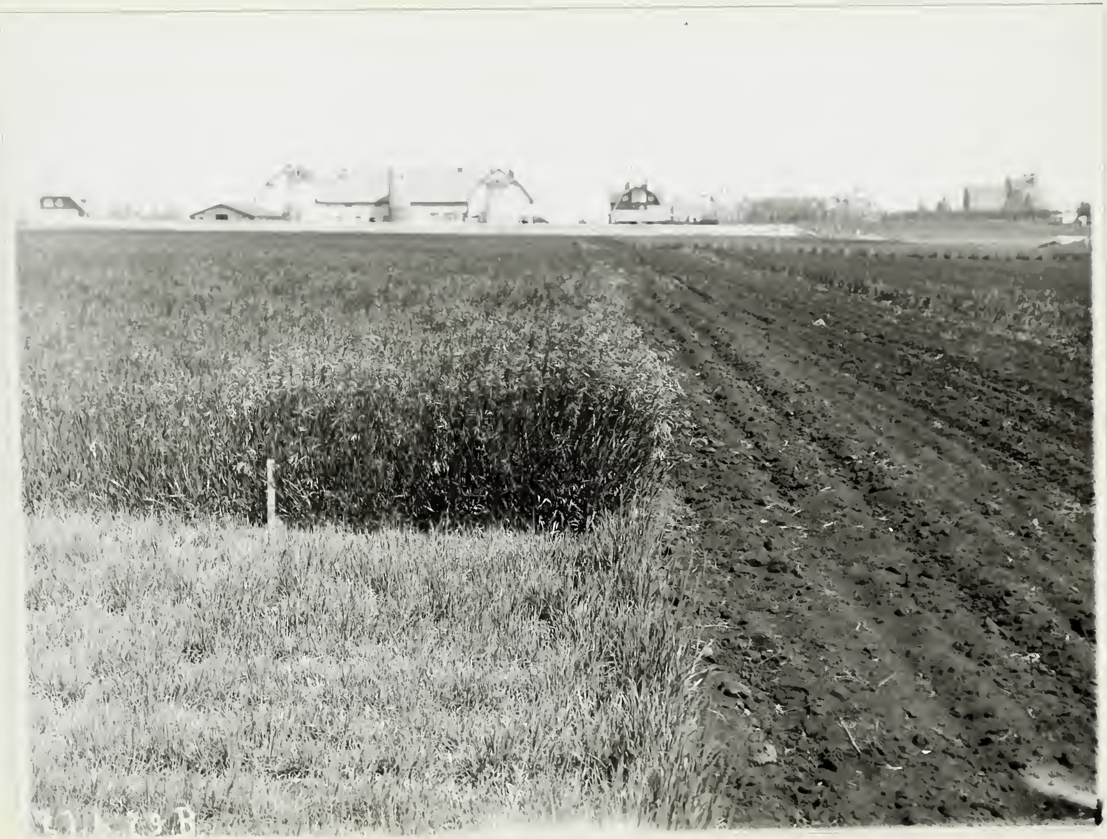


Plate 3.- Superior drought-resistance of brome (in background) over timothy was strikingly demonstrated in 1929. Note border effect on timothy.

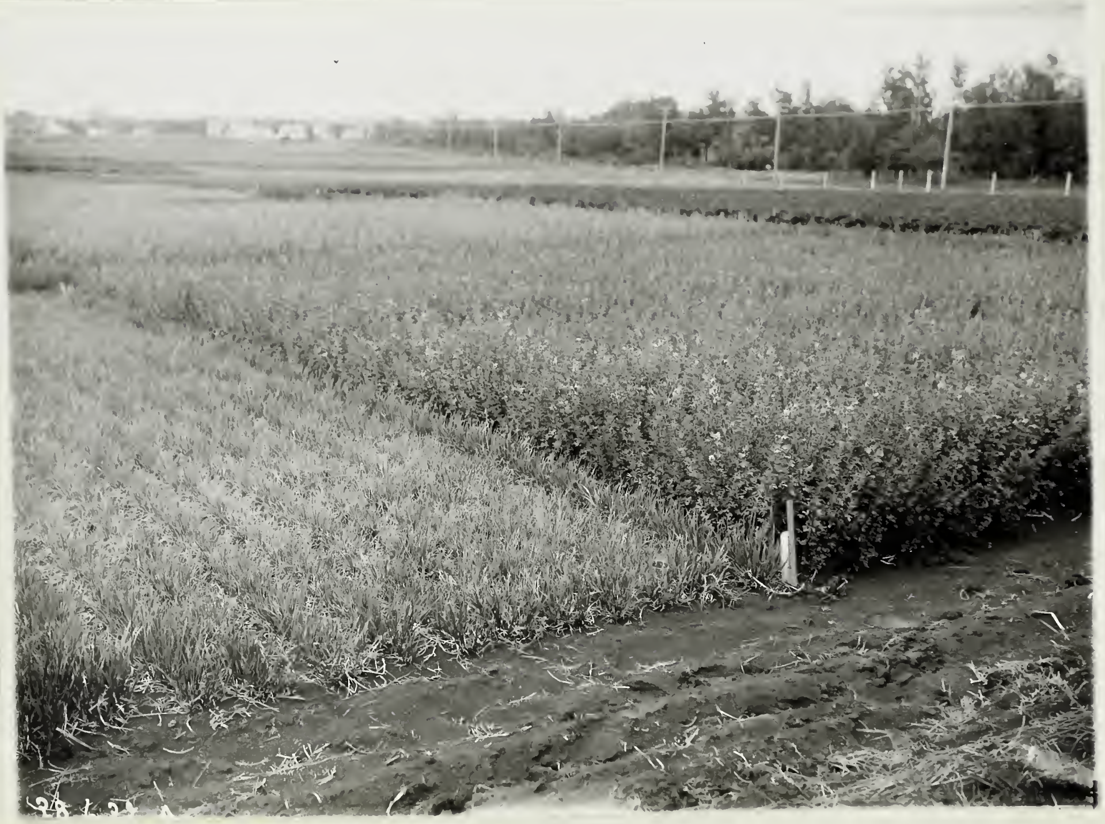


Plate 4.- Comparison of growth of alfalfa (on right) and timothy (on left) during the dry season of 1929.

Plates 2,3, and 4 show the differences in growth of these crops under the dry conditions of 1929.

The nitrogen content of the hays stood in the order: Alfalfa, timothy, western rye, and brome grass. The nitrogen content of the timothy was very high due to the stage at which it was harvested. This result is in harmony with the findings of many other workers (28,37) that young grass is a rich protein food.

Alfalfa removed the largestamount of nitrogen in the hay, followed by western rye grass and brome, with timothy considerably the lowest.

Hay crop of 1929. Second cutting.- With the exception of alfalfa, the crops did not make sufficient growth to warrant a second cutting in 1929. Timothy was particularly poor in this respect, making practically no growth after the first cutting. The yields and nitrogen content of alfalfa cut September 9, are given in Table 5.

Table 5.--Yield and Nitrogen content of hay, Second cutting, 1929.

Crop	Plot No.	Yield (dry basis)	Nitrogen in dry hay.	Nitrogen removed per sub-block	Nitrogen removed per acre
		lbs.	%	lbs.	lbs.
Sub-block II					
Alfalfa	1	40			
	6	37			
	12	34			
	15	42			
	Av.	38	2.85		
	Total	153		4.4	52
Sub-block III					
Alfalfa	2	38			
	5	35			
	11	34			
	16	38			
	Av.	36	2.76		
	Total	145		4.0	47

Relative draft of hay crops on soil.--It is evident that the higher-yielding alfalfa, western rye, and brome remove much greater amounts of moisture and nutrients from the soil than does timothy. Apparently we must look for another reason beside the relative draft on the soil for the explanation of the superiority of grain crops following these three hays as compared with those following timothy.

Yield and Composition of Sods, Sub-block I, 1928.

Prior to the breaking of Sub-block I on July 23, 1928, sod samples were secured in the manner outlined in the plan of the experiment. The weights of the residues are given in Table 6.

Table 6.- Weight of plant residues, 1928. Sub-block I.

Crop	Plot	Sod	Dry weight of plant residues to depth of 6"		
			Roots	Stubble	Total
			gms.	gms.	gms.
Alfalfa	2	A	21.6	13.3	34.9
		B	23.4	13.8	37.2
		C	19.8	12.5	32.3
		D	22.9	10.1	33.0
		Total	87.7	49.7	137.4
	8	A	18.9	9.4	28.3
		B	26.3	11.0	37.3
		C	26.7	13.6	40.3
		D	30.6	17.3	47.9
		Total	102.5	51.3	153.8
	11	A	21.6	12.7	34.3
		B	10.9	6.0	16.9
		C	26.6	20.1	46.7
		D	16.4	12.6	29.0
		Total	75.5	51.4	126.9
	13	A	28.8	16.7	45.5
		B	11.5	9.7	21.2
		C	13.0	9.1	22.1
		D	12.3	6.9	19.2
		Total	65.6	42.4	108.0
Brome	3	A	10.0	11.8	21.8
		B	13.9	19.5	33.4
		C	13.7	21.4	35.1
		D	9.5	12.5	22.0
		Total	47.1	65.2	112.3
	6	A	10.2	12.9	23.1
		B	10.6	15.0	25.6
		C	13.1	13.3	26.4
		D	9.6	11.4	21.0
		Total	44.4	52.6	96.1
	9	A	14.7	13.6	28.3
		B	11.6	12.0	23.6
		C	13.2	20.2	33.4
		D	11.7	17.6	29.3
		Total	51.2	63.4	114.6

Table 6.- (Continued).

Crop	Plot	Sod	Dry weight of plant residues to depth of 6"		
			Roots	Stubble	Total
			gms.	gms.	gms.
Brome	16	A	14.0	13.5	27.5
		B	10.4	12.3	22.7
		C	10.7	11.0	21.7
		D	11.0	14.4	25.4
		Total	46.1	51.2	97.3
Timothy	1	A	15.3	25.5	40.8
		B	16.2	22.1	38.3
		C	8.3	11.9	20.2
		D	11.1	19.9	31.0
		Total	51.0	79.4	130.3
	7	A	23.9	16.6	40.5
		B	18.9	10.2	29.1
		C	24.6	14.1	38.7
		D	14.1	15.7	29.8
		Total	81.4	56.7	138.1
	12	A	13.2	9.3	22.5
		B	15.5	15.4	30.9
		C	13.2	10.6	23.8
		D	16.3	17.5	33.8
		Total	58.2	52.8	111.0
	14	A	9.6	14.4	24.0
		B	14.2	16.7	30.9
		C	14.2	13.8	28.0
		D	11.2	13.2	24.4
		Total	49.1	57.2	106.3
Western rye	4	A	5.1	19.3	24.4
		B	4.9	11.8	16.7
		C	5.2	19.1	24.3
		D	5.4	28.4	33.8
		Total	20.6	78.7	99.2
	5	A	7.1	18.5	25.6
		B	4.7	15.1	19.8
		C	4.8	16.4	21.2
		D	5.1	11.2	16.3
		Total	21.7	61.2	82.9

Table 6.- (Continued).

Crop	Plot	Sod	Dry weight of plant residues to depth of 6"		
			Roots	Stubble	Total
			gms.	gms.	gms.
West[illegible]	10	A	4.3	16.0	20.3
		B	3.9	16.1	20.0
		C	5.7	20.2	25.9
		D	5.4	21.7	27.1
		Total	19.3	74.0	93.3
	15	A	5.3	9.6	14.9
		B	6.1	18.1	24.2
		C	4.2	5.3	9.5
		D	5.6	19.6	25.2
		Total	21.2	52.6	73.8

Considering the difficulties involved in digging the sods and in the separation of the roots and stubble, the weights of the replicates recorded in the preceding table show a surprisingly good agreement. There are, it is true, some large discrepancies, but on the whole the data are satisfactory.

The results of the proximate analysis are given in Table 7.

Table 7.- Proximate analysis of plant residues,1930.Sub-block I.

Crop	Residue	Protein	Crude Fibre	Ash	Ether Extract.	N-free Extract	Moisture
		%	%	%	%	%	%
Alfalfa	Stubble	15.52	37.37	8.77	.89	27.89	9.46
	Roots	12.56	25.45	3.23	3.43	47.16	8.17
Brome	Stubble	8.00	35.21	10.45	1.27	35.24	9.83
	Roots	6.44	32.21	10.09	.39	41.06	9.81
Timothy	Stubble	5.88	24.43	4.73	1.82	51.53	11.61
	Roots	5.75	28.51	10.60	.84	45.49	8.81
Western rye.	Stubble	5.88	37.39	9.34	1.99	37.30	8.10
	Roots	8.38	32.30	9.16	1.45	38.81	9.90

As briefly indicated in the review of the literature, there is ample evidence that a crop residue which contains a low percentage of nitrogen and a high percentage of carbonaceous matter exerts a depressing effect on nitrate formation in soils, which will be reflected in the yield and composition of a subsequent grain crop.

It was to be expected, from previous work on the relative rates of nitrification under alfalfa and timothy sods, that an analysis would reveal alfalfa residues high in nitrogen and low in crude fibre and nitrogen-free extract, and conversely timothy residues low in protein content and high in crude fibre and nitrogen-free extract.

As seen in Table 7, alfalfa residues are highest in protein and timothy residues lowest. Timothy residues, particularly the stubble, are rather lower in crude fibre than the other crops.

Timothy stubble is considerably higher in nitrogen-free extract than is the stubble of other crops, and the content of nitrogen-free extract in the roots of timothy is higher than in the other two grasses but slightly lower than in alfalfa roots.

In Table 8 are shown the dry matter, protein, crude fibre, and carbohydrates (crude fibre + nitrogen-free extract) per acre returned by each crop, when Sub-block I was plowed. Included in the table is the ratio of total carbohydrate to total protein. The protein and crude fibre are the substances which might be expected to exert the greatest influence on the rate of decomposition and nitrification of these residues. The alfalfa is outstandingly high in protein, but the figures for the crude fibre do not show why timothy sod should decompose and nitrify more slowly than brome and western rye grass.

More information is secured from the ratio of total carbohydrates to tatal protein. It will be noticed that for one part of protein incorporated with the soil in these plant residues, alfalfa supplies 5.1 parts of carbohydrate, brome 9.8, western rye 11.8, and timothy 13.2 parts of carbonaceous material.

The higher amount of carbohydrate material for a fixed amount of protein in the residues of the grasses than in alfalfa residues would help to explain the better sequence effect of the legume. The micro-organisms that attack organic matter must obtain a larger portion of nitrogen from the soil where a low amount of protein is present in the residues, and they thereby enter into competition with a succeeding crop for soil nitrates. Since alfalfa residues contain more protein in relation to carbohydrates than do the residues of grasses, a smaller draft is made on soil nitrates and a subsequent wheat crop would be improved in yield and quality.

Table 8.--Crop residues plowed under to a depth of 6 inches in Sub-block 1, 1928.

Crop	Dry Matter			Protein			Crude Fibre			Carbohydrates (Crude fibre + N-free extr.)			Ratio total carbo-hydrates to total protein
	Roots	Stubble	Total	Roots	Stubble	Total	Roots	Stubble	Total	Roots	Stubble	Total	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
Alfalfa	3975	2339	6314	500	369	869	1010	874	1884	2886	1526	4412	5.1
Brome	2264	2788	5052	144	225	369	733	1004	1737	1659	1964	3623	9.8
Timothy	2878	2954	5832	163	169	332	821	721	1542	2130	2244	4374	13.2
Western Rye	992	3200	4192	81	188	269	321	1196	1517	705	2390	3095	11.8

Among the grasses, timothy residues have the widest ratio of carbohydrate to protein. The difference between western rye grass and timothy is smaller than would be expected from their relative sequence effects, while that between western rye and brome is larger.

On the whole, it may be stated that the differences in the ratio of total carbohydrates to total protein in the residues of alfalfa, brome, timothy, and western rye grass indicate that in the decomposition of the grasses, especially the timothy, soil nitrates would be depressed to a greater extent than following a legume sod.

Timothy residues, having the widest $\frac{\text{carbohydrate}}{\text{protein}}$ ratio, would exert a slightly greater adverse effect on a subsequent crop than those of other grasses. This probably helps to explain, in part at least, the inferior sequence effect of this crop.

Yield and Quality of Wheat, Sub-block I.

Wheat was sown on Sub-block I on May 4 and cut on August 26,1929, in the manner described under the plan of the experiment. Owing to the unusually dry season the yields were small. Very little difference could be observed during the summer between the various plots. On harvesting the plots, however, substantial differences were revealed, as shown by the results in Table 9.

Wheat after alfalfa gave the highest yield of grain and straw, followed by western rye and brome, with timothy sod giving the lowest yields.

Table 9. - Yield of wheat following various grasses and alfalfa, Sub-block I, 1929.

Previous crop	Plot	Grain lbs.	Straw lbs.	Grain yield bus.per acre	Straw yield lbs. per acre.
Alfalfa	2	38.5	38.5	30.3	1820
	8	38.5	42.5	30.3	2009
	11	32.0	36.0	25.2	1701
	*13	40.0	42.0	31.5	1985
	Av.	37.2	39.7	29.4	1879
Brome	3	33.0	36.0	26.1	1701
	6	29.5	31.5	23.2	1489
	*9	29.0	29.0	22.8	1371
	16	26.5	27.5	20.9	1300
	Av.	29.5	31.0	23.2	1465
Timothy	1	25.5	30.5	20.1	1441
	7	27.5	30.5	21.7	1441
	12	29.5	29.5	23.2	1394
	14	26.0	30.0	20.5	1418
	Av.	27.1	30.1	21.4	1423
Western rye	4	36.5	40.5	28.8	1914
	5	30.5	33.5	24.0	1583
	10	30.0	32.0	23.6	1512
	15	29.0	27.0	22.8	1276
	Av.	31.5	33.2	24.8	1571

*Yield on Plots 9 and 13 calculated from the half of each plot actually harvested, as the other half was discarded owing to depression in Sub-block I at N.W.corner.

Table 10.--Nitrogen Content of Wheat on Sub-block 1, 1929.

Previous crop	Material	Nitrogen in dry material %	Nitrogen removed		Yield of protein per acre lbs.
			per plot lbs.	per acre lbs.	
Alfalfa	grain	3.08	1.01	47.7	272
	straw	0.71	0.26	12.3	77
	Total		1.27	60.0	349
Brome	grain	3.10	0.81	39.3	224
	straw	0.66	0.19	9.0	56
	Total		1.00	48.3	280
Timothy	grain	3.22	0.77	36.4	207
	straw	0.63	0.17	8.0	50
	Total		0.94	44.4	257
Western Rye	grain	3.29	0.91	43.0	245
	straw	0.57	0.17	8.0	50
	Total		1.08	51.0	295

In Table 10 is shown the nitrogen content of the wheat following alfalfa, brome, timothy, and western rye together with the amount of nitrogen removed in the crop. It will be observed that in regard to quantity of nitrogen removed per acre the wheat crops fall in the descending order: after alfalfa, after western rye, after brome, after timothy.

Samples of wheat following these various crops were taken and their protein, kernel texture, and milling and baking value determined. These results are given in Tables 11,12, and 13.

It will be observed that the protein content is highest in wheat after western rye, closely followed by wheat from timothy plots, with that following alfalfa and brome slightly lower. On the whole the differences in the percentage of protein are small. The protein in the flour follows closely the relative amounts in the wheat.

No significant differences are to be found in the weight per bushel or in the milling test. In kernel texture, wheat after timothy gave a slightly lower percentage of hard kernels. The grades assigned to the samples were practically the same, wheat after brome being classed as a poor No.1 Northern, and the rest as good No.2 Northern, the presence of a few more immature kernels consigning these to the lower grade.

In the baking test by the basic method, Table 12, the flour from wheat after timothy gives slightly poorer results than the other flours.

Baking by the bromate method, as shown in Table 13, however, results in improvement to all flours and especially to the flour from wheat after timothy.

Table 11.--Wheat after various grasses and alfalfa, Sub-block 1, 1929.

Description	Grade	Wt.per bus.as received.	Wt.per bus. (13% moist)	Protein in wheat (13.5% moist)	Milling Test			Protein in flour (13.5% moist)	Kernel Texture		
					Total flour as % wheat	Straight flour as % wheat	Straight flour as % total flour		Hard	Pie-bald	Starchy
		lbs.	lbs.	%				%	%	%	%
Wheat after alfalfa	2°	64.5	62.5	17.2	70.7	67.1	94.8	16.5	99.3	0.2	0.5
Wheat after brome	1°	65.0	62.5	17.2	72.6	68.1	93.7	16.6	99.0	0.2	0.8
Wheat after timothy	2°	64.5	63.5	18.0	74.1	70.1	94.5	17.2	97.9	0.8	1.3
Wheat after Western rye	2°	65.5	63.0	18.3	73.9	69.8	94.4	17.4	99.1	0.2	0.7

Table 12.-Wheat after various grasses and alfalfa, sub-block 1, 1929.
Baking Test (basic method).

Description	Absorption	General appearance		Crumb character		Loaf volume	Baking score
		Color	Form	Color	Texture		
	%					cc.	
Wheat after alfalfa	63.4	4 p	5	5 gy	6.5c	515	65
Wheat after brome	63.3	5	4 f	6 gy	7 c	512	68
Wheat after Timothy	61.9	4 p	4 f	4.5gy	6 c	498	56
Wheat after Western rye	61.0	4.5p	4 f	5 gy	7.5c	503	63

The letters appended to the score indicate the type of fault for which the loaf was scored down, thus;

c -- coarse
f -- flat
gy -- grey-yellow
p -- pale

Table 13.--Wheat after various grasses and alfalfa, Sub-block 1, 1929.

Baking Test (bromate method).

Description	Absorption	General appearance		Crumb character		Loaf volume	Baking score
		Color	Form	Color	Texture		
	%					cc.	
Wheat after alfalfa	63.4	5	5	7gy	7 o	650	98
Wheat after brome	63.3	5	5	8y	9	634	103
Wheat after timothy	61.9	5	5	8y	8 o	674	107
Wheat after Western rye	61.0	5	5	8y	7.5o	636	97

o -- open
gy -- grey-yellow
y -- yellow

It has been demonstrated by a number of workers that in baking experimentally milled flours the simple basic method does not give an accurate estimate of their baking value, since the potentialities of the flour are not clearly shown. Larmour and Macleod (15) have shown that the addition of 0.001 per cent of potassium bromate to the basic formula gives a better estimate of the baking value, since it indicates the response of the flour when subjected to commercial practice. Consequently in this and in succeeding tables the baking results by the bromate method are more important than those where the basic procedure was used.

On the whole it may be stated that the differences in the quality of wheat following these four crops are quite small. It should be noted, however, that owing to the nature of the season all samples are extremely high in protein. With all approaching the maximum possible level, the law of diminishing returns may have operated to prevent variations in protein content of the crop corresponding to differences in rates of nitrification in the soil. That such differences in rates of nitrification existed is evident from the figures in the last column of Table 10. When the total yield of protein in the crop following alfalfa is assigned a value of 100, the crops following western rye grass, brome, and timothy, respectively, have relative values of 85,80, and 74. Since the same variety of wheat was growing on all these plots it is reasonable to assume that the rate of absorption of nitrates in the different plots was proportional to the rate of nitrification.

Determination of Hydrogen-ion Concentration of Soil under Various Grasses and Alfalfa.

It was thought that differences might exist in the acidity of the soil under various crops which would exert an effect on subsequent crops. It is well-known that soil reaction plays an important role in crop adaptation, and in the distribution of plants and soil micro-organisms.

In the Rhode Island experiments (12) onions, which are very sensitive to acid soil conditions, varied in yield from 80 bushels following mangels, cabbages, and rutabagas, the three most alkaline of the crops (in that they remove in the ash more bases than acids and leave the soil more acid) to 520 bushels following red top, an acid-absorbing crop.

With the object of ascertaining whether any differences did exist in the hydrogen-ion concentration of the soil under the different crops, the p H of the soil from Sub-block II was determined in 1929. Composite samples of surface and subsurface, to a depth of 20 inches, were secured and the hydrogen-ion concentration determined, using the hydrogen electrode according to the method outlined by Clark (4), and Snyder (29).

The results are shown in Table 14. The soil reaction for all plots in the block is quite similar, the p H values lying between 6.2 and 6.9. The average p H of the soil from the plots under each crop has the same value, 6.6.

Obviously differences in sequence effect or in microbiological activities of the soil cannot be attributed in this instance to any differences in soil reaction produced by these crops.

Table 14.--Hydrogen-ion concentration of soil under various crops, Sub-block II, 1929.

Crop	Plot	pH
Alfalfa	1	6.2
	6	6.9
	12	6.4
	15	6.7
	Av.	6.6
Brome	2	6.7
	7	6.6
	9	6.7
	16	6.5
	Av.	6.6
Timothy	3	6.8
	8	6.7
	10	6.6
	13	6.3
	Av.	6.6
Western Rye	4	6.6
	5	6.4
	11	6.6
	14	6.7
	Av.	6.6

Oxidation - Reduction Measurements of Plant Residues.

It has long been recognized that a study of oxidation and reduction processes occuring in biological material is of great value, owing to the physiological importance of oxygen to living tissues. Within the last few years, largely through the efforts of W.M. Clark and his co-workers in the Hygienic Laboratory of the United States Public Health Service, a system of measuring the intensity factor of oxidation-reduction by means of electrode potentials has been developed. While numerous points, both in experimental methods and in the interpretation of results, remain to be cleared up, the method has been developed to an extent where it may be applied to many biological problems.

It was thought that the relative rates of decomposition of the residues of alfalfa and the various grasses might be determined by this method. In the ordinary decomposition of organic matter oxygen is used up and carbon dioxide evolved. Gillespie (II) showed that bacterial cultures were normally reducing, and that the addition of an organic substance such as dextrose aids in the production of reducing conditions. It is generally accepted that good soils are normally oxidizing and that reducing conditions are an indication of an unhealthful state of affairs.

Little work has been done on oxidation-reduction potentials of plant materials, the majority of the investigations so far having been directed towards the study of electrode potential measurements of the various indicators of oxidation-reduction.

The method followed in the present experiment was essentially that used by Clark and his associates (5) in a study of oxidation-reduction processes in biological material, and by

Thornton and Hastings (32), working with milk. Owing to a shortage of material, measurements were determined only on the water-soluble portions of the residues.

Five grams of the residue was shaken with 125 cc. of distilled water for $1\frac{1}{2}$ hours. The liquid was rapidly filtered and the electrode potentials determined at 2-hour intervals. Bright platinum electrodes and a saturated potassium chloride calomel half cell were used. The work was carried out at room temperature, 25° C. All readings of E.M.F. are reported in volts in terms of E_h.

The results are shown graphically as potential-time curves in Plate 5. The initial E_h values of the water-soluble parts of the residues are thus seen to lie fairly close together, between + .49 and + .56. The potential change for the first six hours is not great for alfalfa roots or stubble, western rye stubble, or brome roots. With timothy residues the rapid change is still further delayed until the twelfth hour.

The positive E_h limits of the solutions are higher than those reported for bacterial cultures, animal tissues, sewage, or milk. A check on the accuracy of the electrode potentials is of course afforded by determining whether or not the solution will reduce any one of the numerous indicators of oxidation-reduction which reduce at different levels. Unfortunately no dye synthesized as yet is an indicator for an E_h above + .27 volts, so the initial E_h of the solutions cannot be measured by the common oxidation-reduction indicators.

That these solutions in the initial stages were fairly well-poised is indicated by the fact that on shaking the tube containing the solution no change in the electrode potential

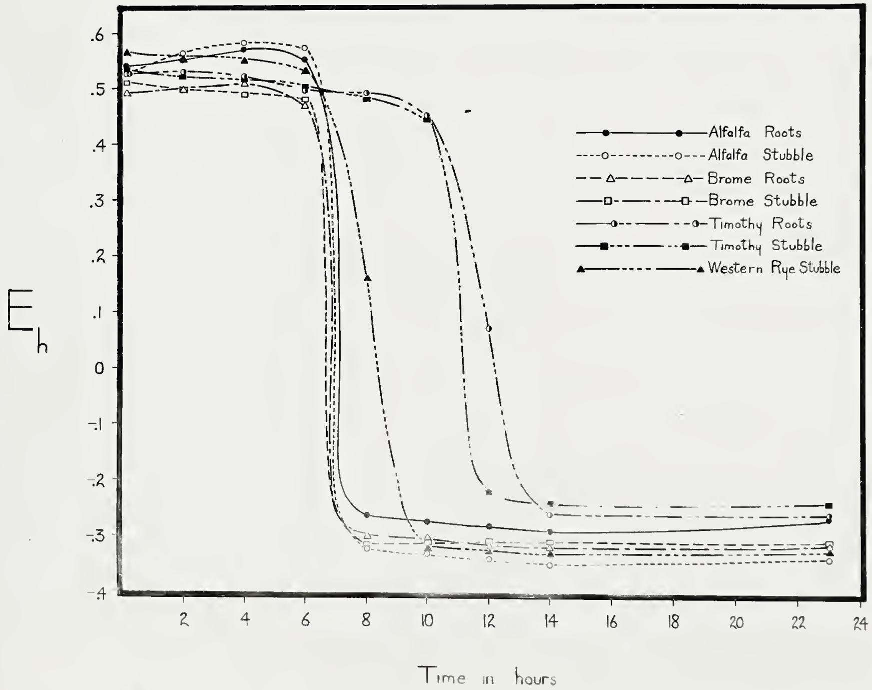


Plate 5.- Potential-time curves of plant residues.

was observed.

The sharp drop in the curve was followed by a nearly constant level of potential. The negative E_h limit for all the residues was between -.24 and - .34 volts. After the drop in the curve, shaking the vessel containing the solution caused the potential to swing almost to the positive extreme. This would seem to indicate that the solution at this stage was not well-poised, since the incorporation of oxygen caused a change in the electrode potential.

One of the most interesting observations in this experiment is the striking similarity between the shape of the potential-time curves of those solutions from plant residues, and those obtained by Thornton and Hastings (32) for milk, an animal fluid.

In conclusion it would appear that while the initial level of electrode potential or the "oxidizable tendency" was nearly the same for all residues, the oxidation-reduction behaviour of the timothy residues was markedly different from that of the other residues, indicating that the decomposition of the water-soluble part of this plant is extended over a longer period than that of the other residues.

The Influence of Crop Sequence on Chemical and Microbiological Changes in the Soil.

As mentioned in the plan of this experiment, a study of the moisture and nitrate changes in the soil under alfalfa and various grass sods is being carried on by the Department of Soils.

In Table 15 are shown moisture and nitrates under alfalfa and grasses to a depth of forty inches. These figures

are averages of Sub-blocks I,II, and III up to July 10, 1928, at which date Sub-block I was broken; then an average of Sub-blocks II and III up to Sept.11,1929. In Table 16 are shown moisture and nitrates on Sub-block I subsequent to breaking the sods, and up to September 11, 1929, after the first wheat crop had been removed.

Table 15.- Moisture and nitrates under various crops to depth of forty inches.

Date	Crop	Moisture %	Nitrate Nitrogen lbs.per acre.
June 15,1927	Alfalfa	30.2	246
	Western rye	30.6	267
	Brome	30.4	245
	Timothy	30.9	250
July 15,1927	Alfalfa	32.8	229
	Western rye	30.8	214
	Brome	31.8	211
	Timothy	31.1	211
Aug.13, 1927	Alfalfa	25.3	210
	Western rye	25.1	171
	Brome	24.7	160
	Timothy	24.2	157
Sept.11,1927	Alfalfa	27.3	140
	Western rye	27.1	132
	Brome	25.5	119
	Timothy	25.1	127
May 17, 1928	Alfalfa	24.3	104
	Western rye	21.8	117
	Brome	21.5	69
	Timothy	22.0	109
June 15,1928	Alfalfa	22.2	80
	Western rye	20.9	76
	Brome	21.1	44
	Timothy	20.8	85
July 10,1928	Alfalfa	25.8	62
	Western rye	24.1	76
	Brome	Not recorded	Not recorded
	Timothy	25.1	83
Aug. 16,1928	Alfalfa	21.0	48
	Western rye	20.9	77
	Brome	20.0	54
	Timothy	20.6	68
Sept.19,1928	Alfalfa	21.6	60
	Western rye	20.0	59
	Brome	20.1	52
	Timothy	19.1	60

Table 15.- (Continued)

Date	Crop	Moisture %	Nitrate Nitrogen lbs per acre.
May 14, 1929	Alfalfa	21.7	38
	Western rye	19.2	Trace
	Brome	22.5	Trace
	Timothy	20.4	Trace
June 14,1929	Alfalfa	13.6	17
	Western rye	12.5	Trace
	Brome	12.5	Trace
	Timothy	13.5	Trace
July 16,1929	Alfalfa	18.2	23
	Western rye	18.1	10
	Brome	17.0	6
	Timothy	18.5	32
Aug. 16,1929	Alfalfa	15.9	16
	Western rye	13.1	4
	Brome	16.5	7
	Timothy	16.8	Trace
Sept 11,1929	Alfalfa	10.5	8
	Western rye	14.2	Trace
	Brome	12.8	Trace
	Timothy	12.9	Trace

Table 16.- Moisture and nitrates on Sub-block I following various crops, to depth of forty inches.

Date	Previous crop	Moisture %	Nitrate Nitrogen lbs.per acre.
Aug.16, 1928	Alfalfa	21.4	85
	Western rye	23.4	84
	Brome	22.8	36
	Timothy	22.1	59
Sept.19,1928	Alfalfa	22.4	161
	Western rye	22.8	131
	Brome	22.0	102
	Timothy	22.3	137
May 14, 1929	Alfalfa	20.5	122
	Western rye	20.8	131
	Brome	20.4	59
	Timothy	19.8	138
June 14,1929	Alfalfa	15.6	198
	Western rye	13.9	114
	Brome	13.5	102
	Timothy	14.0	133
July 16,1929	Alfalfa	19.0	83
	Western rye	18.0	94
	Brome	18.0	66
	Timothy	19.8	58
Aug. 27,1929	Alfalfa	18.0	113
	Western rye	18.2	107
	Brome	15.5	41
	Timothy	19.4	96
Sept.11,1929	Alfalfa	13.2	120
	Western rye	10.1	154
	Brome	13.2	60
	Timothy	14.5	127

In Plate 6 are shown the fluctuations in nitrates under sods (average of Sub-blocks I,II, and III to July 10, 1928; then average of Sub-blocks II and III to Sept. 11, 1929), and the changes in soil nitrate content after breaking the various sods of Sub-block I and sowing to wheat.

The percentages of moisture to a depth of forty inches under the different crops at each date of sampling show practically no significant differences. The sods all appeared to reduce the moisture content of the soil to the same extent.

It is very interesting to observe that during the dry season of 1929 the moisture content of the soil under timothy was no higher than under alfalfa, western rye, or brome grass, notwithstanding the poor growth of the timothy as compared with that of the latter crops. It has usually been assumed that timothy, on account of its less intensively branched root system, was unable to utilize the moisture of the soil as completely as a plant possessing a larger root system. These results, however, would indicate that the explanation for the poor growth of timothy under dry conditions lies in its inefficiency in the use of water.

At the time of planting alfalfa and the various grasses in 1927, nitrates were present in abundance in the soil. Since this time they have steadily declined. This is in accordance with previous findings (22,38) that perennial crops, especially timothy, tend to keep nitrates at a low level throughout the season.

When Sub-block I was broken on July 23, 1928, conditions were rendered favorable for the process of nitrification and the nitrate curves rose sharply, alfalfa plots showing the greatest increase, followed by western rye and timothy. In the spring of 1929 when this Sub-block was sown to wheat, nitrates were highest

after alfalfa sod, followed by timothy and western rye grass. By midsummer the plots following western rye grass and alfalfa were higher in nitrates than those succeeding timothy or brome sod.

In the late summer the nitrates increased on Sub-block I even before the wheat was cut, and with no increase in the moisture content of the soil. This was probably due to the lower demand of the wheat plant for nitrates during the later periods of growth, resulting in an accumulation in the soil. Such a fluctuation in the nitrate curve is often difficult to understand, even by the obvious explanation given above. Newton (25) has suggested that such ~~increases~~ decreases may be due to the ~~liberation~~ absorption of nitrates by micro-organisms other than nitrifying bacteria.

From a study of these changes in the nitrate content of the soil it is apparent that, on the whole, a larger quantity of nitrates are present under alfalfa than under the grasses. Western rye plots usually have a slightly greater nitrate content throughout the season than timothy or brome grass. When these sods are plowed up, and wheat sown on the land, nitrates are highest after alfalfa sod, followed by western rye grass and timothy, with brome lowest.

In 1929 the numbers of bacteria, fungi, and actinomyces in the upper seven inches of soil under alfalfa, timothy, and western rye grass, and under wheat following these crops, were determined at intervals of two weeks throughout the season.

The numbers of bacteria found under alfalfa, timothy, and western rye grass showed no significant differences. The numbers of bacteria under wheat following these crops were alike

and higher than the numbers under the sods. In fact they equalled the bacterial numbers under fallow.

The numbers of fungi under alfalfa were highest and equal to those under fallow, with the numbers under timothy and western rye grass lower. The numbers under wheat after alfalfa were higher than those where wheat followed timothy or western rye grass.

The numbers of actinomyces under all crops were quite irregular and no conclusions could be drawn from the data regarding the numbers of these organisms.

The rate of nitrification of soil, under laboratory conditions, from the plots where wheat followed alfalfa, timothy, and western rye showed no significant differences.

In conclusion, the soil data indicate that biological activity, as measured by nitrate production and plate counts of micro-organisms, is more pronounced in plots where wheat follows alfalfa than where it succeeds grasses. When we attempt to seek an explanation for the adverse sequence effect of timothy as compared with other grasses, it must be admitted that the soil data, as yet, can throw little light on this subject.

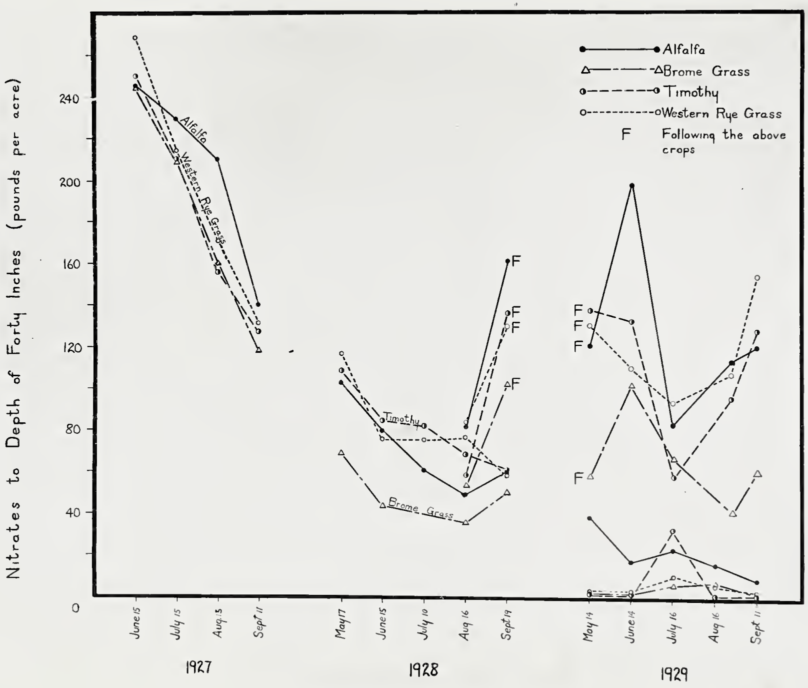


Plate 6.- Fluctuations in nitrates under alfalfa, brome, timothy and western rye grass, and after breaking these sods and sowing to wheat.

THE EFFECT OF INTERPLANTING WITH LEGUMES ON WHEAT YIELD AND QUALITY

Plan of Experiment and Production of Material, 1928.

In 1928 Renfrew wheat was sown May 5th on a block of land on the University farm which had previously been in Renfrew wheat. This block was seeded with the usual roguing paths, but the centre row of each group of five had wheat replaced by inoculated Arctic sweet clover, the whole drilled with a horse drill having a grass-seed attachment.

On one portion of the block the sweet clover was killed by ~~the~~ treatment with 6 percent sulphuric acid, and on the other portion the sweet clover was unaffected. (It should be explained here that the spraying was done in connection with another experiment carried out by the Plant Pathology Division to determine the effect of spraying wheat fields with different concentrations of sulphuric acid on the control of foot and root-rots of cereals.)

The experiment was limited to comparisons of the kernel texture, protein content, and milling and baking value of samples taken from the portion of the block where the sweet clover had been killed by treatment with sulphuric acid and from the portion where the sweet clover was unaffected; and also of composite samples taken from about six places in the single drills adjoining, and one drill removed from, the sweet clover.

Experimental Data, 1928, and Discussion.

The results of these determinations are given in Tables 17 - 19.

Table 17. - Protein, kernel texture, and milling test on wheat interplanted with sweet clover, 1928.

Description	Grade	Wt. per Bus. (13.0% moist)	Protein in Wheat (13.5% moist)	Total Flour	Milling Test		Protein in flour (13.5 moist.	Kernel Texture		
					Str. flour as % wheat	Str. flour as % total flour		Hard	Piebald	Starchy
		lbs.	%	%			%	%	%	%
Wheat with sweet clover	4	58.5	13.3	74.0	66.6	88.8	11.9	98.3	0.6	1.1
Wheat where sweet clover killed.	4	58.0	13.8	71.7	62.8	87.6	10.4	96.3	1.0	2.7
Wheat from rows adjoining sweet clover	4	56.5	11.7	76.2	65.2	85.6	10.6	92.4	2.2	5.4
Wheat from rows one drill distant from sweet clover	4	56.5	12.4	80.4	72.7	90.4	11.2	94.8	1.4	3.8

Table 18.--Baking test (basic method) on wheat interplanted with sweet clover, 1928.

Description	Absorption	General appearance		Crumb character		Loaf volume	Baking score
		Color	Form	Color	Texture		
	%					cc.	
Wheat with sweet clover	64.8	5	5	8.5gy	8.5	522	82
Wheat where sweet clover killed	66.2	4.5p	3.5s	8.5 y	9	504	79
Wheat from rows adjoining sweet clover	63.9	3.5p	4 fs	8 g	8	518	75
Wheat from rows one drill removed from sweet clover	63.2	5	5	6.5 g	7.5c	497	68

c -- coarse
fs -- flat, shredded
g -- grey
gy -- grey-yellow
p -- pale
s -- shell-topped

Table 19.--Baking test (bromate method) on wheat interplanted with sweet clover, 1928.

Description	Absorption	General appearance		Crumb character		Loaf volume	Baking score
		Color	Form	Color	Texture		
	%					cc.	
Wheat with sweet clover	64.8	5	5	8.5 y	9	552	89
Wheat where sweet clover killed	66.2	4.5 p	3 frs	7.5 y	8	455	64
Wheat from rows adjoining sweet clover	64.9	3.5 p	3 f	8 y	7 c	480	64
Wheat from rows one drill removed from sweet clover	64.2	4.5 p	4 f	7.5 g	8	490	70

c -- coarse
f -- flat
f.r.s.-- flat, rough, shell-topped

g -- grey
p -- pale
y -- yellow

It must be remembered that the sample of wheat from the rows one drill distant from the sweet clover cannot be strictly compared with the sample of wheat from the rows adjoining the legume, since the former rows adjoined the roguing paths and would be subject to border effect.

An examination of Tables 17-19 fails to reveal any striking difference between the wheat growing with and without sweet clover.

The wheat associated with sweet clover was slightly lower in protein of wheat, slightly higher in flour yield, protein of flour, and kernel texture than wheat alone. The baking test by the basic method gave a slight advantage, and by the bromate method a larger advantage, to the flour from the wheat associated with sweet clover.

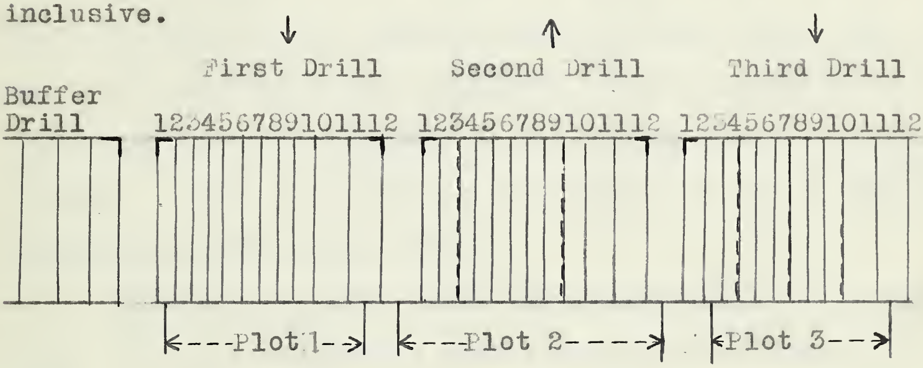
The composite samples of wheat from the rows adjoining, and the rows removed, from the legume give contradictory results in the two methods of baking, and as previously mentioned the results on these two samples are not significant owing to the effect of the paths on wheat from rows one drill removed from sweet clover.

Plan of Experiment and Production of Material, 1929.

In 1929 a more complete experiment was designed. The plan was to compare the yield and quality of wheat in plots where two and three out of twelve drill rows were legumes, with those where all twelve rows were wheat. A block of land in the University Investigation Field comprising Blocks 3A and 3B was sown in this manner on May 2 and 3, 1929, with a horse drill having

a grass-seed attachment. The block was sown in a solid manner, no roguing paths being left. Block 3 A had been in wheat the previous year and was fall-plowed in 1928; 3 B was fallow in 1928. The legumes used were Arctic sweet clover (elite), Grimm alfalfa (Disco no. 19a), and Altaswede red clover. Elite Marquis wheat was used.

The sketch belows shows the east buffer and plots 1 - 3 inclusive.



The arrangement of the plots was as follows:

Buffer - 13 rows wheat (Row 13 to be cut by hand before the rest)

Plot 1 - 10 rows wheat.

Buffer - 1 row wheat to be cut by hand.

Plot 2 - 12 rows, 10 rows wheat, rows 3 and 9 sweet clover.

Buffer - 2 rows wheat to be cut by hand.

Plot 3 - 9 rows, 6 rows wheat, rows 2,5, and 8 sweet clover.

Buffer - 2 rows wheat, to be cut by hand.

Plot 4 - 10 rows wheat.

Buffer - 1 row wheat to be cut by hand.

Plot 5 - similar to plot 2; alfalfa.

Buffer - 2 rows wheat to be cut by hand.

Plot 6 - similar to plot 3; alfalfa.

Buffer - 2 rows wheat to be cut by hand.

Plot 7 - similar to plot 4; wheat only.

Buffer - 1 row wheat to be cut by hand.

Plots 8 to 10 - red clover; similar to plots 2 to 4, with buffers.

Repeat the series (plots 1 to 10) and finish with buffer drill to fill up the block.

It was planned to sample plots, 2, 5, and 8 (and replicates) just before cutting, separate samples being taken from rows 0, 6, and 12 (which were separated from the legumes by two rows) for comparison with rows 2, 4, 8, and 10, those adjacent to the legume. After sampling, the plot was to be cut in bulk for bulk comparison with other plots.

Plots 3, 6, and 9 (and replicates) were to be cut in bulk only, for bulk comparison with other plots in regard to yield, kernel texture, protein content, and milling and baking value.

Unfortunately the extremely dry season of 1929 doomed this experiment to failure. Drought prevented the germination of the legumes except those at the north end of block 3 A, where a depression in the field existed. The first rain came on June 26, at which time no legumes were visible except a few at this low-lying northern portion of the block.

On August 20, just prior to cutting the wheat, samples were taken for grade, kernel texture, and protein test from rows adjacent to, and the third row from the legumes in the part where they had grown. At this date legumes were still found only in the lower portion of the field, and there was no apparent difference between the growth of sweet clover, alfalfa, and red clover, the few plants scattered along the rows being about 6-8 inches high.

Experimental Data, 1929, and Discussion.

Table 20 shows the grade, kernel texture, and protein in these wheat samples.

The wheat adjacent to sweet clover was in both series higher in protein content and percentage of hard kernels than wheat in rows removed from this legume. Wheat adjacent to alfalfa was slightly lower in one series and slightly higher in the other. The kernel texture was almost the same in both cases. Wheat adjacent to red clover was slightly lower in protein than wheat removed from this legume in one series, and in the other contained the same percentage. No differences were observed in kernel texture.

Effect of Volunteer Sweet Clover on Wheat.

In the late summer of 1929, on another part of the University farm devoted to an increase block of Marquis wheat, it was noticed that volunteer sweet clover was quite prevalent in some parts of the field. Six small plots, each 50 by 25 links, were staked out and harvested and threshed separately. Plots 1 and 2 had a thick stand of sweet clover, 3 and 4 a medium stand, and in 5 and 6 no sweet clover was present.

Table 21 shows the yield on these plots. Even a thick stand of volunteer sweet clover did not appear to depress the yield of wheat.

Table 22 gives the protein content, kernel texture, and milling test on wheat from these plots. The protein content

Table 20.- Protein, grade, and kernel texture of wheat interplanted with legumes, 1929.

Description	Protein in wheat	Grade	Kernel Texture		
			Hard	Piebald	Starchy
	%		%	%	%
Sweet clover, plot 2, third row from legume	14.7	1	85.3	3.4	11.3
Sweet clover, plot 2, rows adjacent to legume	15.2	1H	98.0	.8	1.2
Sweet clover, plot 12, third row from legume	13.7	1	89.9	2.8	7.3
Sweet clover, plot 12, rows adjacent to legume	14.0	1	95.4	4.1	2.5
Alfalfa, plot 5, third row from legume	15.8	1H	97.2	1.2	1.6
Alfalfa, plot 5, rows adjacent to legume	15.5	1H	96.4	1.6	2.0
Alfalfa, plot 15, third row from legume	13.8	1	88.0	4.3	7.7
Alfalfa, plot 15, rows adjacent to legume	13.9	1	88.8	2.3	8.9
Red clover, plot 8, third row from legume	13.6	1H	95.0	2.4	2.6
Red clover, plot 8, rows adjacent to legume	13.1	1H	95.1	2.3	2.6
Red clover, plot 18, third row from legume	12.8	1	82.2	3.1	14.7
Red clover, plot 18, rows adjacent to legume	12.8	1	81.2	3.3	15.5

Table 21.- Yield of wheat growing with varying amounts of volunteer sweet clover, 1929.

Plot No.	Description	No. of plants per sq. yd. (approx.)	Yield of grain per plot	Yield of grain per acre
			lbs.	bus.
1	Wheat with thick stand sweet clover.	800	16.5	22.0
2	Wheat with thick stand sweet clover.	800	16.5	22.0
3	Wheat with medium stand sweet clover.	50	19.5	26.0
4	Wheat with medium stand sweet clover.	50	16.5	22.0
5	Wheat with no sweet clover.	0-2	15.5	21.0
6	Wheat with no sweet clover.	0-2	15.5	21.0

Table 22.--Protein content, kernel texture, and milling test on wheat grown with varying amounts of volunteer sweet clover, 1929.

Description	Grade	Wt.per bus.as recei-ved	Wt.per bus. (13% moist)	Protein in wheat (13.5% moist.)	Milling Test			Kernel Texture		
					Total Flour as % as wheat	Straight flour as % wheat	Straight flour as % total flour	Hard	Piebald	Starchy
		lbs.	lbs.	%				%	%	%
Wheat with thick stand sweet clover	2°	65.0	64.0	14.5	70.4	65.0	92.3	90.6	3.4	6.0
Wheat with thick stand sweet clover	2°	64.5	63.0	15.5	70.8	66.5	94.0	88.2	3.2	8.6
Wheat with medium stand sweet clover	2°	64.5	64.0	15.6	72.4	67.3	93.0	71.7	18.7	9.6
Wheat with medium stand sweet clover	2°	65.0	64.5	15.0	73.3	68.1	92.9	68.8	19.4	11.8
Wheat with no sweet clover	2°	65.0	63.0	15.0	71.2	66.4	93.3	70.1	17.8	12.1
Wheat with no sweet clover	1°	65.0	65.0	14.5	71.7	67.1	93.6	81.2	9.5	9.5

and percentage of hard kernels in the wheat associated with a thick growth of sweet clover were higher than in the other plots. These results were therefore similar to those obtained with sweet clover in the experiment reported above.

Tables 23 and 24 give the results of baking tests by basic and bromate methods, respectively, on the wheat from these plots. By the basic method the flour from wheat where no sweet clover was present gave the highest baking score, followed by the plots with a thick stand of this legume. The bromate method, which, as already indicated, gives a better index of baking value than the basic method, gave an advantage to the plots having a thick growth of sweet clover associated with the wheat. The flour from the plots of wheat associated with a medium stand of the legume had a slightly higher baking score than that from plots where no sweet clover was growing with the wheat.

Table 23.- Wheat with varying amounts of volunteer sweet clover, 1929.

Baking test (basic method).

	Absorption	General appearance		Crumb Character		Loaf volume	Baking score
		Color	Form	Color	Texture		
	%					c.c.	
Wheat with thick stand sweet clover	64.1	4 p	4.5f	8y	8	484	69
Wheat with thick stand sweet clover	65.01	5	5	8y	8	509	77
Wheat with medium stand of sweet clover	64.7	4p	4f	7.5y	8c	488	69
Wheat with medium stand of sweet clover	64.8	4p	4fs	7.5y	7.5c	489	68
Wheat without sweet clover	65.2	5	4s	8y	8c	486	71
Wheat without sweet clover	64.6	5	4s	8y	8 0	542	82

c - coarse
f - flat
fs - flat, shredded
o - open
p - pale
s - shredded
y - yellow

Table 24.- Wheat with varying amounts of volunteer sweet clover 1929.

Baking test (bromate method).

	Absorption	General appearance		Crumb character		Loaf volume	Baking score
		Color	Form	Color	Texture		
	%					c.c.	
Wheat with thick stand sweet clover	64.1	4.5p	5	8y	9	518	80
Wheat with thick stand sweet clover	65.0	5	5	8y	9	562	90
Wheat with medium stand sweetclover	64.7	5	5	7y	8	522	77
Wheat with medium stand sweet clover	64.8	5	5	7.5y	9.5	489	76
Wheat with no sweet clover	65.2	5	4.5f	7y	8	495	72
Wheat with no sweet clover	64.6	4.5p	5	7.5y	7.5-0	529	77

f - flat
O - open
p - pale
y - yellow

SUMMARY

As a result of the data secured so far from the sequence and interplanting experiments, the following conclusions may be drawn:

1. Timothy was followed by a lower yield of wheat than alfalfa, western rye grass, or brome grass.
2. Owing to the nature of the season all samples were extremely high in protein, and the differences in the quality of the wheat following alfalfa, western rye grass, brome grass and timothy were small. The yield of protein per acre, however, was highest in wheat after alfalfa, followed by wheat after rye grass, brome grass, and timothy respectively.
3. The adverse effect of timothy on the following wheat crop could not be explained by the relative drain on soil moisture and nutrients of the preceding crops, since timothy removed a great deal less plant food, especially nitrogen, which is usually regarded as the limiting element, from the soil than did alfalfa, western rye, or brome grass.
4. Timothy residues, when plowed under, incorporated in the soil, per acre, more carbonaceous matter for each unit of protein material than did the residues of alfalfa, brome, or western rye grass. Since alfalfa residues contain more protein in relation to carbohydrates than do the residues of the grasses, a smaller draft is made on soil nitrate by micro-organisms decomposing this organic matter. This undoubtedly helps to explain the beneficial sequence effect of alfalfa. Among the grasses the higher ratio of carbo-hydrate to protein in timothy residues than in those of the other crops, probably is responsible,

in considerable measure, for the adverse sequence effect of this crop.

5. No differences were found in the reaction of the soil under alfalfa, western rye grass, brome, or timothy. Apparently sequence effects cannot be explained in this instance by differences in the hydrogen-ion concentration of soil consequent upon growing various crops.
6. Preliminary work on oxidation-reduction potentials of plant residues indicated that the decomposition of the water-soluble portions of timothy residues was extended over a longer period of time than that of the other residues.
7. A study of the chemical and microbiological changes in the soil under the plots of alfalfa, western rye grass, brome, and timothy, and in wheat following these crops, indicated that alfalfa plots have a higher soil nitrate content and a greater biological activity than grass plots, and that this beneficial effect was continued for a year at least after the sods were broken. The differences in soil activities under, and following, western rye grass, brome, and timothy as measured by soil nitrate content, rate of nitrification in soil, and plate counts of micro-organisms were insufficient to account for the varying sequence effects of these grasses. That differences in the rate of nitrification existed is evident from the fact that the yield of protein per acre in wheat following western rye grass was higher than after brome, and considerably higher than in wheat following timothy.
8. The effect of association with legumes on wheat yield and quality has been investigated, but climatic conditions were responsible for the failure of the main experiment designed

to throw light on this subject. Further work must be done before any definite conclusions can be drawn.

9. The results of one experiment indicated that the presence of even a thick stand of volunteer sweet clover did not depress the yield of wheat.
10. On the whole, the results suggested that the quality of wheat can be raised by association with legumes. Whether this increase will be sufficient to warrant interplanting with legumes as a means of raising the quality of wheat is a question that must await further experiments.

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